A LOGGING EQUIPMENT SELECTION SYSTEM FOR INDUSTRIAL PLANTATIONS IN DEVELOPING COUNTRIES

by

WILFRED CHOKENI SINGOGO

Diploma - Forestry, Zambia Forest College, Kitwe, 1968
B.S., Oklahoma State University, 1986

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Steven C. Young
Major Professor

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INTRODUCTION

The selection of suitable logging equipment which is both efficient and economic is one of the most important decisions a forester or logging machine manager must make. However, selecting appropriate machinery sets for varying operating conditions is not easy, even with experience. The importance is indicated by the fact that logging and transport costs may contribute more than half to the final cost of the finished product.

A number of factors compound the problem of equipment selection in forest plantations. Some of these factors are:

1. Different thinning regimes and final cut schedules affect tree size, stand density, and underfoot conditions.
2. Different tree species affect the time to maturity, wood density, and location.
3. Different plantation layouts affect travel distances and production requirements.
4. Varying terrain affects soil conditions, surface roughness, and traction conditions.
5. Different money exchange rates affect the ability to purchase equipment, accessories, and petroleum products.
6. The availability, cost, and skill level of labor may vary widely from location to location.
7. The availability and quality of local service and repair organizations for machinery may vary widely.

8. The capacity of a current machinery set may not be sufficient to meet future harvesting requirements.

These factors, the list of which is by no means complete, complicate the manager's selection of suitable models, sizes, and types of logging equipment. Logging operations can also affect the productivity of subsequent operations, for example, the steady supply of timber to processing mills and pole depots depends upon how efficiently logging operations are performed. Because of this complexity, it is difficult for the manager to foresee the likely consequences of particular equipment decisions related to the purchase of new equipment or the replacement of old equipment. As logging operations increase in magnitude and complexity, there is a need for better methods to aid the manager in the equipment selection process.

OBJECTIVES

The primary objective of this study is to develop a method to assist logging managers in the selection of optimum machinery sets for ground skidding in forest plantations. In order to accomplish this, it is necessary to develop a method of assessing equipment suitability for local conditions. A secondary objective is to demonstrate the applicability of this method using a limited database of logging equipment.

The scope of this study is limited to developing countries, with abundant labor and low wage rates. The project is also confined to ground-skidding methods using agricultural tractors and cable skidders. Emphasis is given to developing methodologies and a framework which is flexible and may be tailored to include local conditions and actual operating data.

REVIEW OF LITERATURE

Timber Harvesting

Timber harvesting includes operations for felling, extraction and long-distance transport of the logged material. A number of sub-operations such as de-limbing, bucking, loading and unloading are also involved. The goal of logging is to deliver timber to the processing mill or consumer in the most desirable form and at a low cost. The major types of logging systems are illustrated in Figure 1. The area studied in this investigation, log extraction, is indicated on the figure.

Tree Stand

The choice and performance of tree-harvesting systems depends on a number of interrelated factors. These are: plantation stands, tree size, area to be harvested, and cost. In general, as the area to be harvested increases or the tree volume per unit area increases, the logging costs per unit of production decrease. In short-rotation, intensive-culture biomass plantations Curtin and Barnett (1986) and Woodfin and Frederick (1987) found that tree size was the single most important factor to consider in scheduling plantation harvesting.

Man-made forest plantations consist of numerous sub-plots commonly called compartments. Depending on the silvicultural practices the trees in the different compartments will be at different stages of growth and thus the logging manager must schedule different tasks (eg., thinning or final cut) for the various compartments.

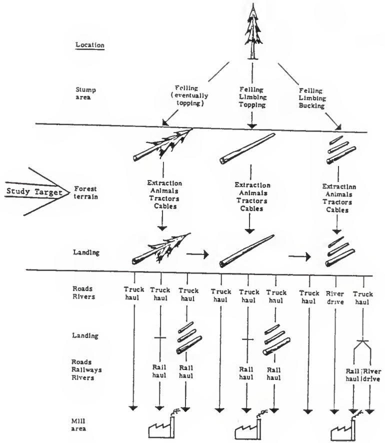

Figure 1. Major types of logging systems. The target area of this study is indicated on the diagram. (Adopted from FAO, 1976).

It is the job of the logging equipment to extract the trees from the interior of the compartment, or stump area, to the roadside or landing area. Three major logging systems are used to accomplish this: shortwood, tree length, and full tree (FAO, 1976). Often more than one system may be used in the same plantation. For example, in the Zambian Industrial Plantations (ZIP) shortwood and tree length methods are used to extract pines and eucalypts.

In a full tree logging system the entire tree is extracted from the stump area to the roadside or landing area. No de-limbing or bucking is done. Whereas, a tree length logging system the tree is de-limbed and bucked at the stump area. The tree is extracted as one whole log to the landing area. A shortwood system implies that trees are de-limbed, bucked, and converted into desired log lengths at the stump area. Skidding methods are usually used with full tree and tree length systems, whereas forwarding is usually used with the shortwood system.

Thinning

In commercial thinning operations, particularly in first and second thinnings, the productivity of harvesting systems is adversely affected by closely spaced small diameter trees which machines must maneuver around. Skidding equipment which is suitable in these areas should be small and highly maneuverable to avoid damage to residual trees. Skidding by a combination of manual labor and low-cost simple machinery is ideal. The shortwood method is more productive in these operations but, tree length methods are also used.

Final Cut

As tree size and maneuvering space increase in third thinning and final cut areas larger and more powerful machines for harvesting are needed. Due to large tree size, machine productivity is expected to be higher. The tree length method of logging is more suited for stands of large trees. The skidding equipment for these areas is specialized and expensive. Ground surface conditions, due to tree debris may limit use of some types of skidding equipment.

Extraction

Extraction involves the transportation of trees from the stump area to the roadside or landing and sometimes to the mill if the distance is short. There are three major methods of extraction:

a. animal skidding/forwarding systems.

b. Tractor/skidder/forwarder systems.

c. cable systems.

In most forest plantations, natural conditions of topography terrain and soil are comparatively favorable and, therefore, the tractor/skidder/forwarder systems are more applicable in ground skidding. However, gullys and ruts due to soil erosion, soil moisture condition, and surface debris in final cut areas can create some problems for mechanization.

Extraction of trees in thinning operations requires serious consideration of the residual stand because of the damage which can be caused by extraction equipment. Traditionally, because of both economics and applicability, agricultural tractors have been used for

extraction in first and second thinning operations because they are able to maneuver easily in limited spaces. However, in third thinning and final cut operations, larger specialized skidders are generally recommended.

Forwarding

Forwarding is the transportation of timber from stump area to roadside or landing by carrying the whole load above the ground. It is usually applied to short wood methods. The timber is carried in special trailers which are either manually or mechanically loaded. Because this method can be labor intensive it may be suitable in developing countries where labor is cheap and low-cost vehicles (agricultural tractors and trailers) can be used for transportation (FAO, 1976).

However, specially designed four-wheel-drive articulated forwarders equipped with knuckleboom loaders and integral carriers on the rear chassis, are used in forwarding operations of developed countries where labor may be neither cheap nor abundant.

Skidding

Skidding is the transportation of trees or logs from the stump area to the roadside or landing by dragging. The logs are partially suspended by a mechanical winch so that the trees can be hauled butt-end or top-end first. The FAO (1976) states that when using this method 60 percent of the load is carried by the skidder. The Caterpillar Tractor Company (1988) points out that the weight transfer may vary between 50-67 percent depending on log size and taper.

Traditionally, animal power has been used for skidding in many parts of the world and is still used in some countries. In the ZIP, all skidding is done with machines. This may be due to the limitations of animal skidding in tropical climates coupled with the extensive nature of the logging operations in Industrial Plantations.

There are two main categories of skidding machines: agricultural tractors and special purpose 4/6-wheel drive articulated machines, commonly called skidders. In either case, the machines are equipped with a winch, cable and chokers for dragging logs. There are several variations of the the special purpose skidders, for example, grapple and clam bunk skidders; but for the purpose of this research only agricultural tractors and four-wheel drive articulated skidders are considered.

Labor and Machine Costs

To meet the goal of lowest possible cost to achieve the desired level of production, logging managers must balance productivity and cost. To get the greatest output from machines at a minimum cost, the manager must determine the cost per unit of production and production per unit of time for each machine in every logging operation (CAT, 1988). Costs have a great influence on profit and the cost of each of the input factors affecting the performance of a machine must be considered.

Labor Costs

In skidding operations labor is needed as operators and handymen (chokermen). The cost of labor includes wages and fringe benefits in

form of housing, annual leave, and other allowances which are usually absorbed by the employer. These costs should be included as part of the machine's operating cost. However, there are studies which exclude labor costs (FAO, 1976). In developing countries labor costs are very small compared to the other factors affecting machine costs.

Machine Costs

There are a number of methods for determining the cost of operating and owning equipment for logging operations. Actual cost data obtained from records of field operations would provide the best cost data for logging machines. In most cases actual data is not available and machine costs must be estimated.

Machine costs are classified as either ownership costs, or operating costs. Ownership costs, which are also called fixed costs, are costs which remain constant regardless of the amount of time that a machine is used. They are costs the owner must bear for owning a machine. Costs which vary with the amount of use of a machine are called operating, or variable, costs (Finner, 1977).

Cubbage and Werblow (1985) determined operating and fixed costs of logging equipment. They compared these costs with 15 years of cost data and found that the development and adoption of new equipment was beneficial to forestry.

To establish meaningful operating costs, extraction machines such as tractors, skidders, and forwarders are evaluated based on the productive machine hours (PMH), (FAO, 1976). The ratio of the annual PMH

to the total number of hours available for machine operation in a year is termed the availability of the machine.

The separate items considered as making up the cost of logging equipment are:

Ownership Costs (Fixed)	Operating Costs (Variable)
Depreciation	Repairs and maintenance
Interest on investment	Fuel and Lubricants
Taxes	Labor
Insurance	Tires
Housing	

Machine Life

It is difficult to precisely determine the economic life of machinery because of many factors that affect the length of time the machinery is in use (Hunt, 1977). Some of the important factors are: operating conditions, maintenance practices and technological obsolescence. Good service support and regular maintenance can extend the economic life of a machine whereas, poor maintenance and severe operating conditions can reduce machine life.

In plantations, where close supervision of logging machinery, knowledge of operating conditions and maintenance are possible, good estimates of machine life can be made(FAO, 1976).

Estimating Ownership Costs

As a machine ages its value declines. To protect and recover the original investment in equipment, the machine owner must determine and

recover an amount equal to the loss in market-value due to depreciation. Additionally, the owner must recover the costs associated with interest, insurance, shelter, and taxes (CAT, 1988).

There are various methods of calculating depreciation for costing purposes. The FAO (1976) and CAT(1988) recommend the "straight line" method which is based on the number of years or hours the owner expects to use the machine during its life. They both agree that other methods may be useful for accounting and tax purposes.

The total amount to be depreciated should include import duties, sales taxes, transportation charges, and any other delivery costs to the machine owner, less the estimated salvage-value (trade-in). In many cases the salvage value is assumed to be some percentage (often 10) of the delivered cost.

Estimating Operating Costs

The cost of repair and maintenance may be the largest operating expense for timber harvesting machinery. Repair and maintenance costs can range from one to two and one-half times the original cost of the equipment over the life of a machine (Stenzel et al., 1985). Because of the difficulty in establishing estimates of repair and maintenance costs for new equipment unless costs of similar equipment working under similar conditions are known, the standard practice is to estimate machine repair and maintenance costs as a percentage of the delivered cost. A method recommended by FAO (1976) for plantations in developing countries assumes that this percentage is 100; however, it

seems reasonable that this percentage should depend on the machine type and the suitability of the machine for the task it is performing.

Other operating costs include fuel, lubricant, and tire costs. Fuel consumption depends upon engine power and the load factor. Fuel consumption can be determined by a number of methods. According to the Standards of the American Society of Agricultural Engineers (ASAE, 1988) fuel consumption can be estimated: (1) for specific operations, (2) on a whole year basis, and (3) from Nebraska Tractor Reports. The ASAE standards also recommend that, in the absence of other data, lubricant costs are typically fifteen percent of the fuel costs. Tire costs are estimated on the basis of tire life and replacement costs. Tire cost estimates should also cover tire repair costs, if necessary.

Estimating machine capacity

It is difficult to determine machine production capacities because of the many factors which affect machine performance in logging systems. Caterpillar tractor Company, in its performance handbook gives general guidelines and data for estimating machine capacities (CAT, 1988). Depending on specific local plantation conditions, the following factors may influence machine performance:

1. Average log weight in the plantation stand.
2. Operating weight of the machine and the weight transfer of the load.
3. Number of logs per haul.
4. Maximum number of logs per haul.
5. Number of trees removed (yield) per hectare.

6. Total area to be harvested.
7. Total resistance, which may consist of:
   a. rolling resistance,
   b. skidding resistance,
   c. grade resistance,
   d. tractive resistance, as affected by moisture conditions and types of soil.
8. Payload (kg), as influenced by machine hauling capability and optimum load capacity.
9. Travel speed and distance.
10. Time to travel, load, and unload.
11. Machine availability as influenced by down-time and service intervals.

All pertinent data from these factors should be determined to establish machine production per unit time.

Machine Selection

Although considerable research has been conducted on timber harvesting equipment selection in developed countries, such as in the United States, little or no research has been conducted in developing countries, specifically in the man-made forests of the African Savannas. It was not possible to find published studies of specific logging machine selection practices for African Savanna plantations. It is assumed that current machinery selection is based on the forester's experience, knowledge of local conditions, and rules of thumb.

There is a basic difference in the approach to mechanization of logging operations between developed and developing countries. Developed countries, due to high wage rates, put greater emphasis on the use of complex, high-capacity, one-operator machines. Whereas, developing countries with abundant and relatively cheap labor, prefer the use of semi-mechanized methods which are labor intensive, FAO (Anon., 1976). This FAO study recommends that, depending on the situation, high capacity machines could be introduced in developing countries to facilitate the work and improve productivity, especially in situations where manpower work is too strenuous and animal power is unavailable. The Forestry Department of FAO in Rome has published many papers on forest management in the African Savanna plantations which contain useful information on logging systems and possible log extraction methods (FAO, 1976).

Another FAO study, (FAO, 1977), provides guidelines to help the forest manager select appropriate forest logging systems and equipment to suit plantation conditions.

Decision Making Aids

In the United States, a number of computer programs have been developed to assist logging managers in equipment selection for timber harvesting systems. Reisinger et al. (1988) evaluated three microcomputer-based programs for analyzing harvesting systems and found that these programs had a common goal of making use of quantitative methods to reduce costs, improve operating efficiency, and assist in decision making. The three programs evaluated were: Auburn Har-

vesting Analyzer; Harvesting System Analyzer; and Harvesting System Simulator. The Auburn System Analyzer was developed using a spread sheet and the other two programs used computer programming languages.

All these programs could be applicable under IP conditions in developing countries except that they fail to address three factors: the availability of cheap labor, the reputation of the local machine dealers, and the availability of replacement parts. These are very important factors to consider in a developing country where most logging equipment is bought from manufacturers outside the country with very limited foreign exchange. The ideal program for use in a developing country should consider machine systems that use the readily available labor supply and evaluate the maintenance services, and parts availability in the developing country.

Computer programs may offer an efficient means of technology transfer to developing countries. Computer technology is relatively cheap and computer hardware, particularly personal computers, are becoming readily available. The transfer of technology from experts in developed countries to users in developing countries is less complex and faster when using computers. Often computer programs can interact with the user in a way which written materials can't or which would be very expensive and time consuming for human experts (Gaultney, 1987). A program may be in several places at once, whereas a single expert can only be in one place. For these reasons a logging equipment selection system computer program seems to be a feasible means of assisting logging managers in the selection of optimum machinery sets for ground skidding in forest plantations in developing

countries.

Computer programs which have been written to aid in decision making have used a multitude of technologies, software packages, and languages. The programming approaches which were considered to be the most applicable for equipment selection are: database programs, linear program models, and expert systems. Each have their own set of advantages and disadvantages.

Database programs are an obvious choice for an equipment selection program simply because the selection process requires a substantial amount of data to be gathered and associated with each machine which is to be considered. Database programs are used in situations where it is desirable to select and sequence subgroups of data from the main database. It is very easy to search and sort the data in many different forms (Krumm, 1988).

Linear programming (LP) is defined as a method of allocating limited resources to competing activities in an optimal manner (Buongiorno and Gilles, 1987). It is designed to solve complex managerial decision problems which are common in many fields (Frazer, 1968).

In forestry, the models that are applicable to forest management can be used to assist the forest manager in showing feasible alternatives and help him determine the best one(s). The models can also be used to help in decision-making through maximization and minimization of certain resources subject to some set of constraints (Buongiorno et al 1987). LP models are very appropriate to logging operations where it is necessary to choose among limited resources of money, labor and equipment to accomplish the logging schedule.

A somewhat new type of decision making aid is an expert system. An expert system is a computer program which simulates the reasoning of a human expert to solve problems (Harmon and King, 1985). Expert systems use rules-of-thumb to arrive at sound decisions in the absence of complete data or information. The fact that expert systems are designed to make use of rules-of-thumb and fuzzy information is what separates them from most other decision making aids. Although this type of program is powerful it is not suitable for all situations. Problems whose solution is almost entirely subjective are the best candidates for expert systems.

METHODS AND PROCEDURES

It was decided that a computer program would offer an efficient and useful method of assisting logging managers with the selection of optimum machinery sets for ground skidding in forest plantations. Therefore, a Logging Equipment Selection System (LESS) was developed to meet this objective. The methods and procedures used to develop LESS are discussed in this chapter.

In the initial stages of this investigation it was thought that this problem may be a likely candidate for an expert system, however, as development began it became obvious that the problem could be easily solved using a database and LP model in combination. Dbase III+, a popular database software package for personal computers, was used to implement the database portion of LESS because of its popularity and availability at a wide number of installations. The LP portion of LESS uses a standard simplex algorithm and is written in the C programming language.

The assembly of data and the formulation of the LESS program required three significant steps. First, harvesting task data, machine performance requirements and economic factors important to skidding decisions had to be identified and determined. This information was categorized and organized into database files. Second, database programs were developed to compute machine costs and capacities using information contained in the database files. Finally, the cost and capacity information was analyzed by the LP model which identified the least cost machinery set to accomplish the specified tasks. The program output includes a list of recommended machinery and the actions required

to assemble the recommended machinery set. The assembly of data and the steps in the formulation of the logging equipment selection system are shown in Figure 2.

A database program was chosen to store all of the data associated with the logging equipment selection system. This choice was made for two reasons: first the data is easy to enter and modify to suit specific conditions at the location where the program is being used. Thus, this approach allows for maximum flexibility. For instance, the value stored for the tractive efficiencies of different types of machines can be modified to account for local traction conditions. Secondly, the database makes it easy to store and retrieve the data associated with particular machines and dealers. The database already has built in capabilities for adding, deleting, and modifying entries.

Selection Factors

In order to accomodate some of the subjective evaluations that are a part of the machine selection process, a system of rating different machine selection factors was created.

A number of selection factors are subjectively evaluated by the user to rate a machine's suitability under local conditions. These selection factors were selected because they are considered to be the most important factors affecting machine selection in a developing country. The selection factors are associated with a particular machine, a particular dealer/manufacturer or a particular machine type. It is the user's responsibility to subjectively assign ratings on a scale of 0-100, with 100 being the best. For instance, if a dealer/manufacturer's

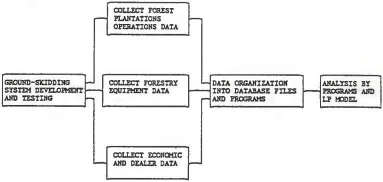

Figure 2. Steps in the formulation of the logging equipment selection system.

reputation is questionable the user may choose to assign a rating of 50. Whereas if the user is totally familiar with the type of technology used on a machine, he may give a rating of 100. The first case is an example of a selection factor rating assigned to a dealer, the second case is an example of a selection factor rating assigned to a particular machine. The individual selection factors considered are as follows:

Dealer/Manufacturer Reputation

One of the most important factors to be considered is the dealer/manufacturer reputation for forest machines in a particular country or local place. This factor incorporates the user's satisfaction with equipment already owned and the user's perception of the level of commitment the dealer manufacturer has for support in the country. This is a factor associated with a particular dealer/manufacturer.

Dealer/Manufacturer Parts Availability

If parts for a machine under consideration are readily available locally or if arrangements can easily be made to buy replacement parts for the particular machine, high rating scores can be given for the parts availability factor. This is a factor associated with a particular dealer/manufacturer.

Dealer/Manufacturer Training

Due to inadequate knowledge in machine operation and maintenance in developing countries, the provision of basic training to both machine operators and mechanics is considered to be very essential in extending equipment economic life. Similar training could be provided to manage-

ment as well if the dealer/manufacturer wishes to show high level and long term commitment. This is a factor associated with a particular dealer/manufacturer.

Dealer/Manufacturer Service

For a dealer/manufacturer to give proper service support for its machines sold in a country, there must be an adequate repair and service organization to ensure early and effective repair of unserviceable machines if called upon to do so. The organization should be set up and equipped to carry out major repairs and overhauls and supply exchange parts. This is a factor associated with a particular dealer/manufacturer.

Machine Technology Familiarity

This is the rating that indicates how familiar the machine owner is with the technology used on the machine. For example, how much the user knows about the hydraulics or electricity systems installed on the machine. Can the present operators and mechanics handle this technology with ease and confidence?

If not, then the rating should reflect this situation and vice versa. But if the user is considering a model of a machine he already owns, perhaps he is familiar with its technology. This is a factor associated with a particular machine.

Machine Cooling System

Because of tough conditions under which these machines work - very dusty and higher ambient air temperatures in tropical countries than temperatures in temperate climates where most of the forest equipment is bought; cooling systems must be satisfactory for these conditions. Engine overheating is a common problem and at times results in complete failure if not corrected in time. This is a factor associated with a particular machine.

Machine Filtration Systems

Filtration of both air and fuel is important due to dusty working conditions in the tropics as pointed out earlier. Diesel engines which cannot get clean and adequate air, and fuel, have poor performance and may fail prematurely. Multi-stage filtration systems of air and diesel fuel are highly recommended in the tropics. This is a factor associated with a particular machine.

Machine Type Suitability

How suitable is the machine being considered for the particular logging operation? A number of factors can be considered when answering this question. Among these are: operator and general safety in the plantation, machine type suitability, and consideration for labor/machine interaction. This is a factor associated with a particular machine type.

Weighting the Selection Factors

The user can choose to weight any of the selection factors by accessing any of the three databases: dealers.dbf, machines.dbf, and machtype.dbf. Once in these data bases, the user can assign ratings to each selection factor using any scale, for example, 0-10 or 0-100 as long as the same scale is maintained throughout the rating process. The ratings of the individual selection factors are combined (by the rating.prg program) to form an overall rating for a machine. The importance of the overall rating in machine selection is discussed under the rating.prg program.

Overall Program Description

The systematic flow process through which the overall program works is discussed in this section. A flow chart of the system is shown in Figure 3. The steps that the program goes through are described below:

During the first step, the program loads the skidding parameters. Some of the factors considered are, skid speed, skid distance, return speed and skid resistance. The program then computes the the total area to be harvested for each task. Next the economic data is loaded. This data includes the interest, tax, insurance, and shelter rates, fuel cost data and assumed salvage value (expressed as a percentage of the purchase price) of machinery. The program then loads weighting constants which the user can modify to give more or less emphasis to certain selection factors. The program then opens the machines database and proceeds to evaluate the cost and capacity of each machine in every task.

The program computes a rating for each machine on a scale of 0 to 100. This rating is computed by combining the individual ratings of the selection factors, as modified by the weighting constants. The individual ratings are given to particular machines, dealers, and machine types based on subjective evaluations by the user (or possibly by the person who originally installed the program). Next the machine life and fixed cost of the machine are computed. The program will read information about a machine's capacity from a database if this information is entered or if it is not, it will estimate the capacity of the machine in each of the tasks to be performed. Next, variable costs are computed (or, if provided, read from a database file).

This process continues until all machines have been evaluated in all tasks. All the while the cost and capacity information is stored in a file for use by the linear programming program. When the evaluation process is complete the linear programming model is called and the linear program computes the least cost machinery set to complete all of the specified tasks.

Database Description

Database files and database programs were developed and grouped in a modular form so that users can easily get to the information needed. For example, all information about economic factors can be found in the "economic.dbf" database file.

The following is a list of the database files along with a short description of the type of information that they contain. A complete listing of database structures is presented in Appendix A.

1. **compartment.dbf** - Contains information about the particular compartments in the plantation; for example, area, skid distance, and expected skid and return speed information is included.

2. **tasks.dbf** - Contains information about the various tasks to be performed and task related information, like number of trees per hectare, tree density, and tree volume.

3. **skid.dbf** - Contains performance information which affects all machines in all tasks. Information such as skid resistance, maximum number of chokers and tire life are included here.

4. **economic.dbf** - Contains economic information which is common to all machines in all tasks; for example, interest rate, fuel price, and salvage value. In situations where no taxes or insurance are paid, a zero specification by the user will indicate that such economic elements are not included in machinery costing.

5. **machtype.dbf** - Contains information which is common to all machines of a given type. For the purpose of this study two-wheel drive tractors are considered as one machine type, four-wheel drive tractors another, and skidders another. Information contained here includes, tractive efficiency, machine life, and machine type suitability.

6. **machines.dbf** - Contains information specific to a particular machine, such as price, power, dealer and name.

7. **dealers**.dbf - Contains information about machine dealers and manufacturers, such as name, reputation, parts availability, and service support.

8. **exchange**.dbf - Contains information about the monetary exchange rate for different currencies.

9. **cost_cap**.dbf - Contains cost and/or capacity information for particular machines in particular tasks. If no entry is found for a machine/task combination, the cost and capacity is estimated. The capability to enter actual cost and capacity information is included primarily for machines which are already owned and accurate cost records exist.

10. **weights**.dbf - Contains weighting constants for the selection factors. These constants are used to control the amount of emphasis given to the individual selection factors when computing the overall rating of the machine. The selection factors are: dealer reputation, machine type suitability, parts availability, familiarity with the technology used on a particular machine, cooling system adequacy, and filtration system adequacy. The user may choose to weight the factors however he sees fit. However, in most developing countries, the overriding factors are the availability of dealer/manufacturer service and the availability of parts. If the level of support (parts availability and service) is high, usually a machine will have a longer life and therefore be more cost effective.

Database Programs

The database programs were developed to compute, process and present information from database files to the user. A complete listing of the database programs can be found in Appendix B. Some of these programs read stored data from database files and organize it into other database files or allocate it to appropriate variables.

Since nobody is capable of supplying all the information that would be required for every situation, default values are supplied for many of the variables. If the user chooses to leave a database file entry blank the default value is used. Default values may be changed by modifying the appropriate database file in which the default entry is contained. The use of default values, speeds up the data entry process and also allows less experienced individuals to use the program.

1. **estimate.prg Program**

   This is the main data coordinating program. The purpose of this program is to get data from other programs and database files and to construct a file which contains cost and capacity information for each machine in each task to be performed. The flowchart of this program is shown in Figure 3.

2. **skid.prg Program**

   This program reads the data from the skid.dbf database file to get the skid parameters. A flowchart of the operation of the skid.prg program is shown in Figure 4.

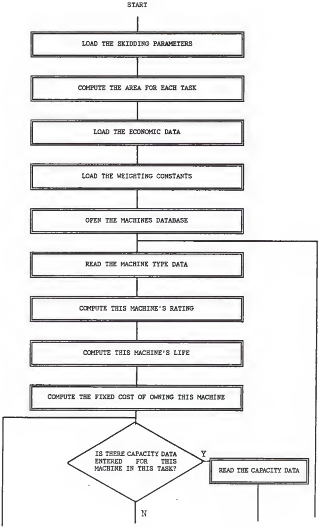

Figure 3. Flowchart of the estimate.prg program.

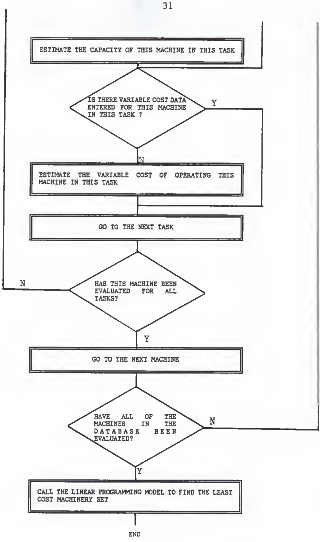

Figure 3. Flowchart of the estimate.prg program (continued).

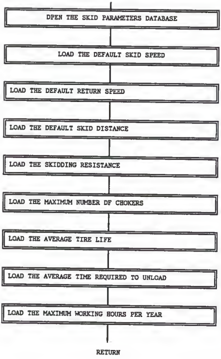

Figure 4. Flowchart for the skid.prg program.

3. **area.prg Program**

Initially, this program checks all the compartments which are scheduled for harvesting. After checking, the program finds the total area that needs to be harvested in each task. The program also computes the average skid speed, return speed, and skid distance for each task. If skid speed, return speed, and skid distance are specified for the compartment, these values are used; otherwise, the default values read from the skid.dbf database are used. A flowchart of the operation of this program is shown in Figure 5.

4. **economic.prg Program**

This program (Figure 6) uses information from the economic.dbf database to set economic variables to their correct value.

5. **weights.prg Program**

This program reads the weighting factors from the wts.dbf database and sets the proper variables to the correct values. A flowchart of this program is shown in Figure 7. The weighting factors are used to control the emphasis which is given to the selection factors.

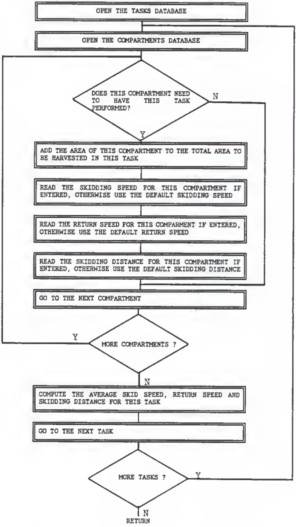

Figure 5. Flowchart of the area.prg program.

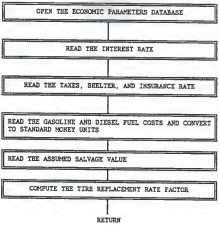

Figure 6. Flowchart for the economic.prg program.

6. **machtype.prg Program**

This program (Figure 8) reads the machtype.dbf database and sets proper variables to their correct values. The basic life is the estimated maximum life of a machine under ideal conditions. The actual life of a machine is shorter than basic life, and depends on a number of factors, including operating conditions, training of operators and mechanics, availability of replacement parts and familiarity with the technology.

7. **rating.prg Program**

The rating.prg program (Figure 9) computes the "overall" rating of a machine. The overall rating is arrived at by considering factors related to the machine, the machine type, and the dealer/manufacturer that sells, services and supplies replacement parts for the machine. The rating is computed from the individual

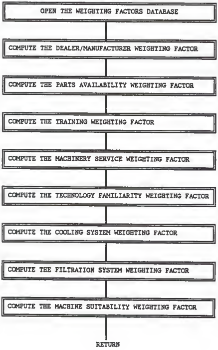

Figure 7. Flowchart for the weights.prg program.

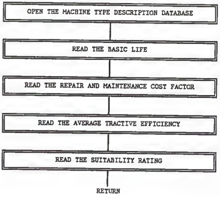

Figure 8. Flowchart of the machtype.prg program.

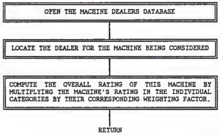

Figure 9. Flowchart for the rating.prg program.

ratings given to the selection factors discussed previously. The contribution of each of the individual ratings to the overall rating is controlled by the weighting constants.

The rating, which is a number between 0 and 100, is very important because it is a composite measure of the suitability of a machine. The higher the rating the better suited the machine is for the operating conditions.

8. life.prg Program

This program (Figure 10) reads the estimated life, if entered, or estimates the life if it is not. The estimated life is simply the product of the basic life and overall rating divided by one-hundred.

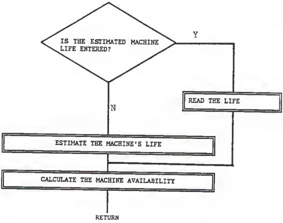

Figure 10. Flowchart for the life.prg program.

Life = Basic Life * Rating/100

Thus, the overall rating modifies the basic life, or maximum life under ideal conditions, to arrive at the estimated life of the machine. The availability is the fraction of the total time that a machine is available to do productive work. This is an important factor and in this case it has also been assumed that the availability is directly related to the overall rating of a machine (Figure 11). It is assumed that a machine with a lower overall rating will have more downtime and need to be serviced more often, reducing its number of productive machine hours.

9. **fcost Program**

This program (Figure 12) computes the fixed cost of a machine. If the fixed cost field is blank, the fixed cost is estimated; otherwise, the fixed cost is read as entered.

Depreciation, the loss in value and capacity of a machine is a major item in the cost of logging equipment. Since the objective of this depreciation is to determine charges to use in computing unit costs of operation, the "straight-line" method is used in this project. The straight-line method reduces the value of a machine by an equal amount each year during its useful life. Figure 13 shows a straight-line depreciation curve and a typical depreciation curve for machines.

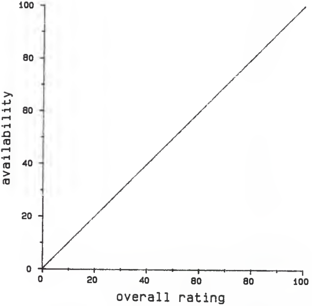

Fig. 11: Overall rating vs. availability.

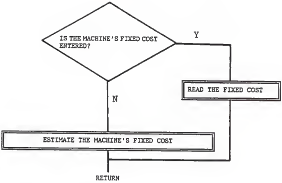

Figure 12. Flowchart of the program for the fcost.prg program.

The program finds the fixed cost per unit time through this equation:

Fixed cost = "Price * (interest rate * (1 + salvage value))/yrs + (1-salvage value)/yrs ~ TSI - rate"

TSI = Taxes, shelter and insurance

This takes into account fixed costs associated with depreciation, interest, taxes, shelter, and insurance costs.

10. capacity.prg Program

This program (Figure 14) determines the capacity of a machine to perform a certain task. If capacity data for the machine to perform this task is found in the cost-cap.dbf database, this information is read from there. If the capacity data is not found, it is estimated based on the power of the machine and the machine type.

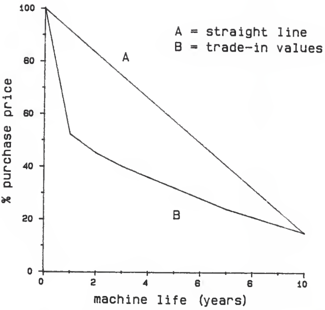

Fig. 13: St. Line VS. Book Value Depreciation

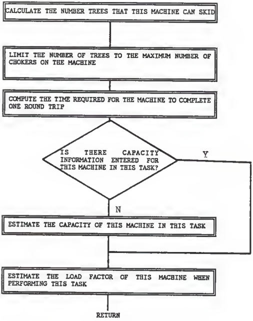

Figure 14. Flowchart of the capacity.prg program.

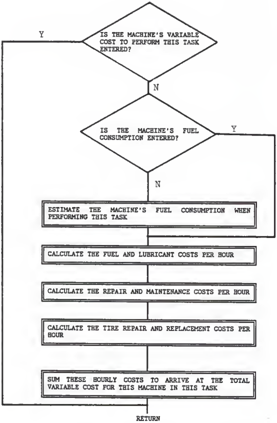

Figure 15. Flowchart for the vcost.prg program.

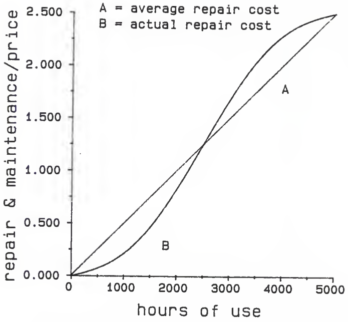

Fig. 16: Accumulated R & M Costs

repair and maintenance costs remain constant over the expected life of a machine. The method used to estimate repair and maintenance costs in this program assumes that costs can be averaged over the life of a machine and that these costs are a certain percentage of the purchase price. This percentage may be specified for each different machine type.

Tires - During the life of a machine several sets of tires will need to purchased. Although this cost occurs in discrete steps as shown in Figure 17b, for the purposes of this program a straight line approximation has been assumed, as shown in Figure 17a. The straight line approximation is the average tire cost over the life of the machine.

12. **cnvmoney.prg Program**

The cnvmoney.prg program (Figure 18) is a currency conversion program which converts a cost, which may be expressed in one of several currencies, to a common currency. This program is a very useful feature, especially where machine and accessory bid prices are quoted in several currencies; usually this is the case with international machine bids (tenders). Any monetary data may be entered into LESS in any one of the currencies defined in the exchange.dbf database. Before making calculations, the program will convert all monetary values to a common base.

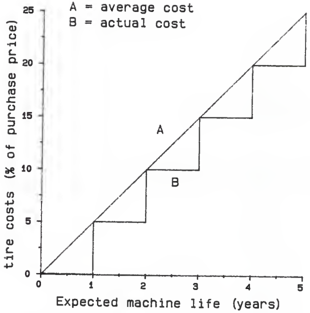

Fig. 17: Relationship between tire replacement cost and machine life.

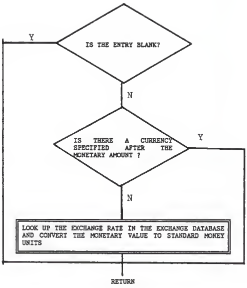

Figure 18. Flowchart for the cnvmoney.prg program.

Linear Programming Model

Finally, the estimate program evokes the linear programming program which uses the cost and capacity data file written by the estimate program. The linear program selects the lowest cost machinery set and describes the actions necessary to assemble the recommended machinery set. A flowchart of the operation of the linear programming program is shown in Figure 19. A complete listing of the LP program, lp.c, can be found in Appendix C.

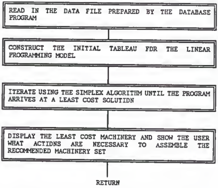

Figure 19. Flowchart for the linear program used to find the least cost machinery set.

RESULTS AND DISCUSSION

The output information from the LESS program is discussed in this chapter. The analyses are presented to show the working concepts of the whole program.

The discussion will focus on the selection results and recommendations of the least cost machinery sets for a single task and then in a situation in which there are four tasks to be performed. In both of the examples presented the same machinery database was used to choose from.

In the first analysis, test case 1, 2620 hectares of first thinning was specified to be completed. For the second analysis, test case 2, a total annual harvesting plan of 10,000 hectares was used: consisting of 2620 hectares in first thinning, 2474 hectares of second thinning, 2299 hectares of third thinning, and 2379 hectares of final cut. A summary of the tasks to be completed in both of the test cases is shown in Table 1.

TABLE 1. Summary of the tasks to be performed for the test cases studied.

Task description	Area ha.	Tree size m^3	Tree density trees/ha.	No. of kg^3	No. of compartments
1st case					
First thinning	2620	.063	350	1000	49
2nd case					
First thinning	2620	.063	350	1000	49
Second thinning	2474	.125	200	1000	55
Third thinning	2299	.500	200	1000	49
Final cut	2379	1.000	220	1000	52

A limited machine database (machines.dbf) of 21 machines, consisting of assorted tractors and special purpose-built skidders was used as a pool for the program to choose from. Some of the machines were specified as already being owned and others were to be considered for purchase. A summary of the machine database used for the test cases is listed in Table 2.

TABLE 2. Summary list of machines used for the selection process.

machine number	dealer number	# units available	# units owned	machine type	power, kw	overall rating
5	1	99	20	4WD	54.0	75
7	1	99	2	4WD	112.0	75
9	2	99	2	skidder	96.0	100
10	2	99	1	skidder	130.0	99
22	4	99	4	2WD	39.0	78
24	4	99	10	2WD	54.0	78
28	4	99	5	4WD	75.0	81
29	4	99	2	4WD	90.0	81
30	4	99	0	4WD	105.0	81
31	4	99	0	4WD	127.0	81
39	7	99	0	skidder	64.0	85
40	7	99	0	skidder	75.0	85
41	7	99	0	skidder	90.0	85
42	7	99	0	skidder	113.0	85
53	7	99	0	2WD	41.0	78
59	7	99	0	2WD	78.0	78
64	8	99	2	skidder	97.0	86
65	8	99	0	skidder	116.0	86
66	8	99	0	skidder	128.0	86
68	8	99	0	skidder	87.0	86
70	8	99	0	skidder	69.0	86

Depending on whether the machines included in the equipment database are owned or available for purchase, the analysis will recommend to buy the deficient number if required and to sell the excess machines if not needed.

Some of the program output will now be presented to illustrate the important features of the LESS program. Complete listings of the output from this program are provided in Appendix D.

Machine Analysis

For test case 1, the recommended machine usage in hours and hectarage are shown in Table 3. The total annual skidding cost, the recommended machinery set, and the actions required to assemble the recommended machinery set are provided in Table 4. In this case the program specified the purchase of 9 small two-wheel drive tractors to harvest the specified hectarage. As can be seen the program chose a small capacity tractor since many of the units were available and labor costs are not significant. In other words, it is cost effective to use several smaller machines rather than a few large capacity machines in this situation. As logical as this sounds for situations where labor costs are insignificant, this recommendation is rarely made by forestry consultants in developing countries. Perhaps this is because most consultants are from developed countries where labor costs are high and high capacity machines are justified.

The program results should not have the final say, as they are only an aid to management in the machine selection process. While aware of the costs involved in the recommended system, the manager should make the final judgment after considering other factors like new equipment and capital availability, old equipment allocation to less demanding operations and the possibility of cannibalizing for spare parts.

The recommendations of the four combined tasks, test case 2, are shown in Tables 5 and 6. Table 7 gives a summary of the machine selection in this case.

TABLE 3. Machine usage in hours and hectares for the least cost machinery set in test case 1.

Task 1 - FIRST THINNING

Machine usage (hours)	
Machine 5	0
Machine 7	0
Machine 9	0
Machine 10	0
Machine 22	0
Machine 24	0
Machine 28	0
Machine 29	0
Machine 30	0
Machine 31	0
Machine 39	0
Machine 40	0
Machine 41	0
Machine 42	0
Machine 53	14869
Machine 59	0
Machine 64	0
Machine 65	0
Machine 66	0
Machine 68	0
Machine 70	0

Machine usage (hectares)	
Machine 5	0
Machine 7	0
Machine 9	0
Machine 10	0
Machine 22	0
Machine 24	0
Machine 28	0
Machine 29	0
Machine 30	0
Machine 31	0
Machine 39	0
Machine 40	0
Machine 41	0
Machine 42	0
Machine 53	2620
Machine 59	0
Machine 64	0
Machine 65	0
Machine 66	0
Machine 68	0
Machine 70	0

TABLE 4. Machine cost and actions required to assemble the least cost machinery set in test case 1.

Task 1 - FIRST THINNING

Machine 5	0
Machine 7	0
Machine 9	0
Machine 10	0
Machine 22	0
Machine 24	0
Machine 28	0
Machine 29	0
Machine 30	0
Machine 31	0
Machine 39	0
Machine 40	0
Machine 41	0
Machine 42	0
Machine 53	233005
Machine 59	0
Machine 64	0
Machine 65	0
Machine 66	0
Machine 68	0
Machine 70	0
Total cost =	233005

The recommended machinery set consists of:

9 --- JD 2355	2 W.D., 4 cyl.

Actions required to assemble the recommended machinery set are:

SELL 20 --- IH 885	4 W.D., 6 cyl.
SELL 2 --- IH 7120	4 W.D., 6 cyl.
SELL 2 --- CAT 518	Skidder
SELL 1 --- CAT 528	Skidder
SELL 4 --- FORD 4610	2 W.D., 4 cyl
SELL 10 --- FORD 6610	2 W.D., 4 cyl.
SELL 5 --- FORD TW5	4 W.D., 6 cyl. with cab
SELL 2 --- FORD TW15	4 W.D., 6 cyl. with cab
BUY 9 --- JD 2355	2 W.D., 4 cyl.
SELL 2 --- TJ 380A	Skidder powershift

TABLE 5. Machine usage in hours and hectares for the least cost machinery set test case 2.

	Task 1	Task 2	Task 3	Task 4
Machine usage (hours)				
Machine 5	0	0	0	0
Machine 7	0	0	0	0
Machine 9	0	0	0	0
Machine 10	0	0	0	0
Machine 22	0	0	0	0
Machine 24	0	0	0	0
Machine 28	0	0	0	0
Machine 29	0	0	0	0
Machine 30	0	0	0	0
Machine 31	0	0	0	0
Machine 39	0	0	0	41958
Machine 40	0	0	0	0
Machine 41	0	0	0	0
Machine 42	0	0	0	0
Machine 53	14869	11572	42574	0
Machine 59	0	0	0	0
Machine 64	0	0	0	0
Machine 65	0	0	0	0
Machine 66	0	0	0	0
Machine 68	0	0	0	0
Machine 70	0	0	0	0
Machine usage (hectares)				
Machine 5	0	0	0	0
Machine 7	0	0	0	0
Machine 9	0	0	0	0
Machine 10	0	0	0	0
Machine 22	0	0	0	0
Machine 24	0	0	0	0
Machine 28	0	0	0	0
Machine 29	0	0	0	0
Machine 30	0	0	0	0
Machine 31	0	0	0	0
Machine 39	0	0	0	2379
Machine 40	0	0	0	0
Machine 41	0	0	0	0
Machine 42	0	0	0	0
Machine 53	2620	2474	2299	0
Machine 59	0	0	0	0
Machine 64	0	0	0	0
Machine 65	0	0	0	0
Machine 66	0	0	0	0
Machine 68	0	0	0	0
Machine 70	0	0	0	0

TABLE 6. Machine usage in hours and hectares for the least cost machinery set in test case 2.

	Task 1	Task 2	Task 3	Task 4
Machine cost ($)				
Machine 5	0	0	0	0
Machine 7	0	0	0	0
Machine 9	0	0	0	0
Machine 10	0	0	0	0
Machine 22	0	0	0	0
Machine 24	0	0	0	0
Machine 28	0	0	0	0
Machine 29	0	0	0	0
Machine 30	0	0	0	0
Machine 31	0	0	0	0
Machine 39	0	0	0	1387121
Machine 40	0	0	0	0
Machine 41	0	0	0	0
Machine 42	0	0	0	0
Machine 53	233005	198915	731848	0
Machine 59	0	0	0	0
Machine 64	0	0	0	0
Machine 65	0	0	0	0
Machine 66	0	0	0	0
Machine 68	0	0	0	0
Machine 70	0	0	0	0
Total cost =	2550889			

The recommended machinery set consists of:

22 --- JD 440D	Skidder
39 --- JD 2355	2 W.D., 4 cyl.

Actions required to assemble the recommended machinery set are:

SELL 20 --- IH 885	4 W.D., 6 cyl.
SELL 2 --- IH 7120	4 W.D., 6 cyl.
SELL 2 --- CAT 518	Skidder
SELL 1 --- CAT 528	Skidder
SELL 4 --- FORD 4610	2 W.D., 4cyl
SELL 10 --- FORD 6610	2 W.D., 4 cyl.
SELL 5 --- FORD TW5	4 W.D., 6 cyl. with cab
SELL 2 --- FORD TW15	4 W.D., 6 cyl. with cab
BUY 22 --- JD 440D	Skidder
BUY 39 --- JD 2355	2 W.D.
SELL 2 --- TJ 380A	Skidder, powershift

TABLE 7. Summary of machine selection.

Task	Ha	# units	machine ID #
1st thinning	2620	9	53
2nd thinning	2474	7	53
3rd thinning	2299	24	53
Final cut	2379	22	39

From Table 7, it can be seen that as tree size increases beyond the capability of certain sizes of machines the choice is for the next most cost-effective machine of higher capacity.

CONCLUSIONS

To find the least cost machinery set for a particular logging system is a complex problem. The choice of machines depends upon numerous factors such as tree size, terrain, skidding distance and above all costs of machine operation and ownership. The use of a database program and a linear programming model reduced this complexity and proved to be successful in the selection of low cost and efficient machinery set in this study. The program properly handled data associated with machine characteristics, field operations, costs and multi-function equations.

Through optimization techniques, an optimal machinery set was determined and additional recommendations made to management to assist in decision making.

The principles of this program have a wide application in the logging industry even though the the factors that constitute the least cost machinery set vary from location to location. The program is flexible enough to be modified and updated according to the situation.

This program has other benefits in addition to skidding equipment selection. The program can also serve as:

1. A decision support system for the logging manager. For example, the program would help in deciding what to do with old machines as they lose capacity and are no longer cost effective. The manager can either relegate old machines to less demanding tasks, sell them or cannibalize for spare parts.

2. A planning tool to plan logging operations effectively, purchase equipment in a timely manner, and monitor equipment repair and maintenance.

3. A resource allocation tool to keep a close watch on costs and capacities of forest equipment in logging operations.

4. A business organization tool which allows the manager to maintain and update management principles associated with logging and equipment decisions.

SUGGESTIONS FOR FUTURE RESEARCH

This investigation indicated some areas where further work is needed. Further study is needed to test and verify the program in real field situations, ideally in plantations in a developing country. Another study to find the best method of transferring this technology to a developing country may be necessary. The equipment database should be expanded to include as much forestry equipment as possible.

To complete the extraction system, forwarders and manually loaded trailers pulled by agricultural tractors should be included. The program will need to be modified and updated to include these machine types.

To complete the whole timber harvesting process (Figure 1), the remaining logging operations, that is, felling and long-distance transportation should also be included in the analysis. This would allow the evaluation of costs associated with the whole timber harvesting process.

REFERENCES

1. Allan, T.G., and F. Endean. 1966. Manual of plantation techniques. Departmental Instruction. Lusaka, Zambia Forest Department.

2. Allison, C.E. 1970. Plantations workstudy manual. Departmental Guide. Ndola, Zambia.

3. American Society of Agricultural Engineers. 1988. Agricultural engineers yearbook of standards. ASAE, St. Joseph, MI.

4. Buongiorno, J., and K. Gilles. 1987. Forest management and economics. MacMillan Publishing Co., NY.

5. Caterpillar Tractor Company. 1988. Caterpillar performance handbook. edition 19. Caterpillar, Peoria, IL.

6. Cubbage, F.W., and D.A. Werblow. 1985. Trends in forest harvesting equipment costs. Paper presented at the American Society of Agricultural Engineers Meeting, Chicago, IL.

7. Cullen, D.E., and W.J. Barr. 1980. Harvesting of close-spaced short-rotation woody biomass. U.S. Department of Energy. Mathtec, Inc., Princeton, NJ.

8. Curtin, D.T., and P.E. Barnett. 1986. Development of forest harvesting technology: Application in short rotation intensive culture (SRIC) woody biomass. Technical Note B58. Tennessee Valley Authority, Div. of Land and Economic Resources.

9. Davis, C.W. 1976. The forester's pocket reckoner. Departmental Guide. Ndola, Zambia.

10. Deveria, N. 1972. Plantation mechanization in industrial plantations. Forest Industries Feasibility Study, Zambia. Rome, FAO. FOI: SF/Zam 5.

11. Finner, M.F. 1978. Farm machinery fundamentals. American Publishing Co.

12. Food and Agriculture Organization of the United Nations. 1976. Harvesting man-made forests in developing countries. United Nations, Rome.

13. Food and Agriculture Organization of the United Nations. 1977. Planning forest roads and harvesting systems. United Nations, Rome.

14. Frazer, J.R. 1968. Applied linear programming. Prentice-Hall, Inc., Englewood Cliffs, NJ.

15. Gaulteney, L. D. 1987. A decision support system for technology transfer. Paper presented at the American Society of Agricultural Engineers Meeting.Chcago,IL.

16. Gass, S.I. 1964. Linear programming methods and applications. International Business Machines, Inc., McGraw-Hill Book Co., NY.

17. Harmon, P., and D. King. 1985. Artificial intelligence in business: Expert systems. John Wiley and Sons, Inc., NY.

18. Hendricks, G., and D. Curtin. 1985. Harvesting system analyzer (HSA) program. Tennessee Valley Authority.

19. Hunt, D. 1983. Farm power and machinery management. Iowa State University Press, Ames.

20. Krumm, R. 1988. Getting more from spread sheets and databases: How to choose the best program for your work. Family and Home Office Computing 6(1): 40-42.

21. Laurie, M.V. 1974. Tree planting practices in African Savannas. Food and Agriculture Organization of the United Nations, Rome.

22. Nkaonja, R.S.W. 1984. Plantations for timber production in Africa. (D.L. Hawksworth, ed.) Proc. of CAB's First Scientific Conference, Arusha, Tanzania.

23. Reisinger, T.W., W.D. Greene, and J.F. McNeel. 1988. Microcomputer software for analyzing harvesting systems. Southern Journal of Applied Forestry 12:37-67.

24. Simpson, A. 1986. Understanding dBASE III PLUS. Sybex, Inc., Alameda, CA.

25. Simpson, A. 1987. dBASE III PLUS programmer's reference guide. Sybex, Inc., Alameda, CA.

26. Staaf, K.A.G., and N.A. Wiksten. 1984. Tree harvesting techniques. Martinus Nijhoff Publishers, Boston.

27. Stenzel, G., T.A. Walbridge, and J.K. Pearce. 1985. Logging and pulpwood production. John Wiley & Sons Publishing Co.

28. Woodfin, S., D. Frederick, and B. Stokes. 1987. Selected harvesting machines for short rotation intensive culture biomass plantations. Paper presented at the American Society of Agricultural Engineers Meeting, Chicago, IL.

APPENDIX A

DATABASE STRUCTURES

Structure for database: C:skid.dbf
Number of data records: 1
Date of last update : 03/08/89

Field	Field Name	Type	Width	Dec
1	SKID_SPD	Numeric	4	1
2	RETURN_SPD	Numeric	4	1
3	SKID_DIST	Numeric	4	
4	SKID_RESIS	Numeric	4	2
5	MAX_CHOKES	Numeric	2	
6	TIRE_LIFE	Numeric	5	
7	UNLOD_TIME	Numeric	2	
8	HOURS	Numeric	4	
** Total **			30	

Structure for database: C:compart.dbf
Number of data records: 208
Date of last update : 03/17/89

Field	Field Name	Type	Width	Dec
1	COMPART_NO	Numeric	3	
2	NAME	Character	65	
3	AREA	Numeric	5	1
4	SKID_DIST	Character	4	
5	TASK_NO	Numeric	2	
6	SKID_SPD	Character	4	
7	RETURN_SPD	Character	4	
** Total **			88	

Structure for database: C:tasks.dbf
Number of data records: 4
Date of last update : 03/05/89

Field	Field Name	Type	Width	Dec
1	TASK_NO	Numeric	2	
2	NAME	Character	65	
3	NUM_TREES	Numeric	4	
4	TREE_DENS	Numeric	4	
5	TREE_VOL	Numeric	6	3
6	TIME_P_TRE	Numeric	4	2
** Total **			86	

Structure for database: C:weights.dbf
Number of data records: 1
Date of last update : 03/23/89

Field	Field Name	Type	Width	Dec
1	REPUTA_WT	Numeric	2	
2	PARTS_WT	Numeric	2	
3	TRAIN_WT	Numeric	2	
4	SERVICE_WT	Numeric	2	
5	FAMILR_WT	Numeric	2	
6	COOLING_WT	Numeric	2	
7	FILTER_WT	Numeric	2	
8	SUIT_WT	Numeric	2	
** Total **			17	

```
Structure for database: C:economic.dbf
Number of data records:        1
Date of last update   : 03/23/89
Field  Field Name  Type       Width    Dec
    1  INT_RATE    Numeric        6      3
    2  TSI_RATE    Numeric        6      3
    3  GAS_PRICE   Character     12
    4  DSL_PRICE   Character     12
    5  SALVAGE     Numeric        5      2
    6  TIRE_RATE   Numeric        3
** Total **                      45
```

```
Structure for database: C:exchange.dbf
Number of data records:        3
Date of last update   : 03/05/89
Field  Field Name  Type       Width    Dec
    1  SYMBOL      Character      3
    2  NAME        Character     65
    3  EXCH_RATE   Numeric        9      4
** Total **                      78
```

```
Structure for database: C:cost_cap.dbf
Number of data records:        0
Date of last update   : 03/08/89
Field  Field Name  Type       Width    Dec
    1  MACH_NO     Numeric        3
    2  TASK_NO     Numeric        2
    3  COST        Character     12
    4  CAPACITY    Character     12
** Total **                      30
```

```
Structure for database: C:dealers.dbf
Number of data records:       7
Date of last update   : 03/20/89
Field  Field Name  Type       Width    Dec
    1  DEALER_NO   Numeric        2
    2  NAME        Character     65
    3  REPUTATION  Numeric        3
    4  PARTS       Numeric        3
    5  TRAINING    Numeric        3
    6  SERVICE     Numeric        3
** Total **                      80
```

```
Structure for database: C:machines.dbf
Number of data records:      21
Date of last update   : 03/23/89
Field  Field Name  Type       Width    Dec
    1  MACH_NO     Numeric        3
    2  NAME        Character     65
    3  YEAR        Character      4
    4  ACC_HOURS   Numeric        5
    5  MACH_TYPE   Numeric        2
    6  ATTACH_NO   Numeric        2
    7  POWER       Numeric        5      1
    8  WEIGHT      Numeric        5
    9  FUEL_TYPE   Character      1
   10  FUEL_CONS   Character      5
   11  DEALER_NO   Numeric        2
   12  LIFE        Character      6
   13  FIXED_COST  Character     12
   14  PRICE       Character     12
   15  NUM_OWNED   Numeric        2
   16  NUM_AVAIL   Numeric        2
   17  FAMILIAR    Numeric        3
   18  COOLING     Numeric        3
   19  FILTRATION  Numeric        3
** Total **                     143
```

```
Structure for database: C:machtype.dbf
Number of data records:       3
Date of last update   : 03/23/89
Field  Field Name  Type       Width    Dec
    1  MACH_TYPE   Numeric        2
    2  NAME        Character     65
    3  BASIC_LIFE  Numeric        5
    4  RM_RATE     Numeric        3
    5  TRACT_EFF   Numeric        2
    6  SUITABLE    Numeric        3
** Total **                      81
```

APPENDIX B

DATABASE PROGRAMS

```
***************** ld_skid.prg ***********************************
***
*** this program reads the skid.dbf database to get the skid parameters
*** and sets the proper public variables to the correct values
*****************************************************************
use skid
D_SKID_SPD = skid_spd             && default skid speed, km/h
D_RTRN_SPD = return_spd           && default return speed, km/h
D_SKID_DIS = skid_dist            && default skid distance
SKID_RESIS = skid_resis           && skid resistance
MAX_CHOKES = max_chokes           && maximum number of chokes
TIRE_LIFE  = tire_life            && average tire life, hours
UNLOD_TIME = unlod_time           && time to unload a haul, minutes
HOURS      = hours                && max hours a machine can be used
use
```

```
******************** area.prg ******************************
***
*** this program checks all of the compartments and totalizes the
*** area that needs to be harvested in each task.  The program also
*** computes the average skid speed, return speed, and skid distance
*** for each task.  If skid speed, return speed, and skid distance are
*** specified for a compartment those values are used, otherwise the
*** default values (from skid.dbf) are used
**************************************************************
select a
use tasks
NUM_TASKS = 0
do while .not. eof()
   tot_area = 0.
   temp1 = 0.
   temp2 = 0.
   temp3 = 0.
   select b
   use compart
   && for the compartments that are using this task
   locate for task_no = tasks->task_no
   do while .not. eof()
      tot_area = tot_area + compart->area
      if len(trim(compart->skid_spd)) # 0
         temp1 = temp1 + val(compart->skid_spd)*compart->area
      else
         temp1 = temp1 + D_SKID_SPD*compart->area
      endif
      if len(trim(compart->return_spd)) # 0
         temp2 = temp2 + val(compart->return_spd)*compart->area
      else
         temp2 = temp2 + D_RTRN_SPD*compart->area
      endif
      if len(trim(compart->skid_dist)) # 0
         temp3 = temp3 + val(compart->skid_dist)*compart->area
      else
         temp3 = temp3 + D_SKID_DIS*compart->area
      endif
      continue
   enddo
   if tot_area > 0
      NUM_TASKS = NUM_TASKS + 1
              &&create global variables for this task
              SUB = ltrim(str(num_tasks))
              public TASK_NUM&SUB
              public TRE_P_KW&SUB
              public TRV_TIME&SUB
              public ARE_P_TRE&SUB
```

```
            public TIM_P_TRE&SUB

            TASK_NUM&SUB = tasks->task_no
            area_&SUB = tot_area
            s_spd   = templ/tot_area
            r_spd = temp2/tot_area
            s_dist  = temp3/tot_area
            pull_p_kw  = 0.8 * 3.6 / s_spd
            mass_p_kw  = 1000 * pull_p_kw / 9.81 / SKID_RESIS
            mass_p_tre = tasks->tree_dens * tasks->tree_vol
            mass_p_are = mass_p_tre * tasks->num_trees
            TRE_P_KW&SUB = mass_p_kw / mass_p_tre
            TRV_TIME&SUB = (s_dist/s_spd + s_dist/r_spd)/1000
            ARE_P_TRE&SUB = mass_p_tre / mass_p_are
            TIM_P_TRE&SUB= tasks->time_p_tre
   endif
   select a
   skip
enddo

&& write the number of active tasks to the output file
&& write the area of each active task to the output file
set alternate on
? NUM_TASKS
i = 1
use tasks
do while i <= NUM_TASKS
  SUB = ltrim(str(i))
  do while tasks->task_no # TASK_NUM&SUB
     skip
  enddo
  ?ltrim(str(TASK_NUM&SUB)), ltrim(str(area_&SUB,12,2)), tasks->name
  i = i+1
enddo
set alternate off
```

```
            s_dist  = temp3/tot_area
            pull_p_kw  = 0.8 * 3.6 / s_spd
            mass_p_kw  = 1000 * pull_p_kw / 9.81 / SKID_RESIS
            mass_p_tre = tasks->tree_dens * tasks->tree_vol
            mass_p_are = mass_p_tre * tasks->num_trees
            TRE_P_KW&SUB = mass_p_kw / mass_p_tre
            TRV_TIME&SUB = (s_dist/s_spd + s_dist/r_spd)/1000
            ARE_P_TRE&SUB = mass_p_tre / mass_p_are
            TIM_P_TRE&SUB= tasks->time_p_tre
   endif
   select a
   skip
enddo

&& write the number of active tasks to the output file
&& write the area of each active task to the output file
set alternate on
? NUM_TASKS
i = 1
use tasks
do while i <= NUM_TASKS
  SUB = ltrim(str(i))
  do while tasks->task_no # TASK_NUM&SUB
     skip
  enddo
  ?ltrim(str(TASK_NUM&SUB)), ltrim(str(area_&SUB,12,2)), tasks->name
  i = i+1
enddo
set alternate off
```

```
****************** ld_econ.prg *********************
***
***  this program uses the economic database to set
***  some of the public variables to their correct
***  values
****************************************************

use economic
INT_RATE   = int_rate/100.       && interest rate, decimal (eg. 0.1 =
10%)
TSI_RATE   = tsi_rate/100.      && annual taxes, shelter, and insurance
price = gas_price
***** find the gasoline price, standard money units
do cnvmoney with price, GAS_PRICE, blank
price = dsl_price
***** diesel price, standard money units
do cnvmoney with price, DSL_PRICE, blank
SALVAGE    = salvage/100.       && salvage value, decimal of purchase
price
TIRE_COST  = tire_rate/100./TIRE_LIFE  && tire replacement cost/hr
use
```

```
*************************** ld_wts.prg *******************************
***
*** this program reads the weighting factors from the weights database
*** and sets the proper public variables to the correct values.
*** The public variable weights are normalized so that the sum of the
*** weights is one.
**********************************************************************
use weights
sum_wts    = reputa_wt + parts_wt + train_wt + service_wt + ;
             familr_wt  + cooling_wt + filter_wt + suit_wt
REPUTA_WT  = reputa_wt/sum_wts
PARTS_WT   = parts_wt/sum_wts
TRAIN_WT   = train_wt/sum_wts
SERVICE_WT = service_wt/sum_wts
FAMILR_WT  = familr_wt/sum_wts
COOLING_WT = cooling_wt/sum_wts
FILTER_WT  = filter_wt/sum_wts
SUIT_WT    = suit_wt/sum_wts
use
```

```
*************************** machtype.prg **************************
****
**** This program reads the machtype database and sets the proper
**** public variables to their correct values
********************************************************************

select b
use machtype
locate for mach_type = machines->mach_type
BASIC_LIFE = basic_life                       && basic life of this type
machine
RM_COST    = rm_rate/100./BASIC_LIFE          && repair and maintenance
cost/hr
TRACT_EFF  = tract_eff/100.
SUITABLE = suitable
use
```

```
**************************** rating.prg **********************************
***
***  This program computes the "overall" rating for the machine
***  currently being processed.  This overall rating is arrived at by
***  considering factors related to the machine and the dealer/
***  manufacturer that sells, services, and manufactures the machine
**************************************************************************

select b
use dealers

&&find the dealer for this machine

locate for dealer_no = machines-> dealer_no

&& compute the overall rating

RATING = reputation * REPUTA_WT + parts * PARTS_WT +  ;
         training   * TRAIN_WT  + service * SERVICE_WT + ;
         machines->familiar * FAMILR_WT + machines->cooling * COOLING_WT
+ ;
         machines->filtration * FILTER_WT + SUITABLE * SUIT_WT

use
```

```
**************************** life.prg **********************************
***
*** This program gets the life (in hours) of a machine
*** If the life is entered it is read, if the life is not entered it
*** is estimated.
************************************************************************
***
&& get the machine's life in hours
if len(trim(machines->life)) = 0
    && if machine life is not entered -- estimate it
        LIFE = round( BASIC_LIFE * RATING / 100, 0)
else
    && read the life
        LIFE = val(machines->life)
endif
AVAILABLE = HOURS * RATING / 100                    && hours available per
year

set alternate on
? machines->name
&& write the availability data to the output file
? machines->mach_no, machines->num_owned, machines->num_avail
set decimals to 0
set fixed on
?? min( AVAILABLE, LIFE ), LIFE, RATING
set fixed off
set alternate off
```

```
****************************** capacity.prg ************************
*** This program gets the capacity of a machine to perform a task.
*** If capacity data for the machine performing this task is found
*** in the cost_cap database this information is read from there.  ***
Otherwise the capacity is estimated.
**********************************************************************
        max_trees = machines->power*TRACT_EFF*TRE_P_KW&SUB
        tree_p_lod = min(max_trees, max_chokes)
*       ? 'tree_p_lod =',tree_p_lod
        cycle_time = TRV_TIME&SUB + ;
                     (UNLOD_TIME + TIM_P_TRE&SUB * tree_p_lod)/60
*       ? 'cycle_time =', cycle_time

        && if an entry for the capacity is found and not blank, read it
        if found() .and. len(trim(cost_cap->capacity)) # 0
            TASK_CAP = val(cost_cap->capacity)
        else
            && otherwise estimate the capacity
            TASK_CAP = ARE_P_TRE&SUB * tree_p_lod / cycle_time
*           ? 'capacity =', TASK_CAP, 'ha/hr'
       endif
       LOAD_FACT = 0.8 * TASK_CAP * cycle_time / (ARE_P_TRE&SUB *
max_trees)
*      ? 'LOAD_FACT =', LOAD_FACT
```

```
************************** fcost.prg ***********************************
******
****** This program gets the fixed cost of a machine
****** If the fixed cost field is blank the fixed cost is
****** estimated otherwise the fixed cost is read as entered.
***********************************************************************
***
&& read the fixed cost
do cnvmoney with machines->fixed_cost, FIXED_COST, blank
     if blank
        && then estimate it
        do cnvmoney with machines->price, PRICE, blank
             if blank
                 ?"ERROR -- MACHINE PRICE NOT FOUND"
             else
                 FIXED_COST = PRICE * ( ;
                                INT_RATE * (1 + SALVAGE) / 2. / AVAILABLE
;
                              + (1 - SALVAGE) / LIFE ;
                              + TSI_RATE / AVAILABLE )
             endif
     endif
```

```
****************************** vcost.prg ******************************
***
*** This program gets the variable cost of a machine to perform a certain
*** task.  If variable cost data for the machine performing this task is
*** found in the cost_cap database this information is read from there.
*** Otherwise the variable cost is estimated.
*************************************************************************
***

        if found()
            cost = cost_cap->cost
            do cnvmoney with cost, VAR_COST, blank
        endif

        if .not. found() .or. blank
            && do the estimate

            && read this machine's fuel consumption if not blank
            if len(trim(machines->fuel_cons)) # 0
                fuel_cons = val(machines->fuel_cons)
            else
                && if no entry for fuel consumption, estimate it
                if upper(machines->fuel_type) = 'G'
                     && estimate for gas engines, liters/kW-h
                     fuel_cons = (2.74*LOAD_FACT + 3.15 - ;
                                  0.2*sqrt(697*LOAD_FACT))*GAS_PRICE
                else
                     && estimate for diesel engines, liters/kW-h
                     fuel_cons = (2.64*LOAD_FACT + 3.91 - ;
                         0.2*sqrt(738*LOAD_FACT + 173))*DSL_PRICE
                endif
            endif
*           ? 'fuel_cons =', fuel_cons, 'cost/kw-hr'
            fuel_p_hr = 1.15 * machines->power*LOAD_FACT*fuel_cons
           ? 'fuel_p_hr =', fuel_p_hr, 'cost/hr'
            rm_p_hr   = PRICE * RM_COST
           ? 'rm_p_hr=', rm_p_hr, 'cost/hr'
            tire_p_hr = PRICE * TIRE_COST
           ? 'tire_p_hr =', tire_p_hr, 'cost/hr'
            VAR_COST = fuel_p_hr + rm_p_hr + tire_p_hr
           ? 'var cost = ',VAR_COST, 'cost/hr'
        endif
```

```
****************************** cnvmoney.Prg
* converts a cost which may be expressed in one of several currencies
* to a common currency for calculations
* the value to be converted consists of a string which has 2 substrings
* the first substring is the cost (all digits) and the second substring
* is the currency that the cost is expressed in.
* eg. 10000 wgm  Is 10000 west german marks
* or  80000 us$  is 80000 u.s. dollars
*
* the currency expression must match one of the symbols in
* the exchange database in order to be valid
* if the second substring is not present then the currency is assumed
* to be the common currency

procedure cnvmoney

parameters string, money, blank
if len(trim(string)) = 0               && if the entry is blank
    blank = .t.                        &&    then return blank as true
else
    blank = .f.
    money  = val(string)               && otherwise convert it
    temp = ltrim(string)
    if len(temp) > 0
       i = 1
       do while i <= len(temp)
         if isalpha(substr(temp,i))
           exit
         else
           i=i+1
         endif
       enddo
       if i <= len(temp)
          temp = rtrim(substr(temp,i))
          select d
          use exchange
          locate for ltrim(rtrim(exchange->symbol)) = temp
          if found()
             money = money*exchange->exch_rate
          else
             ?'ERROR -- money symbol',temp,' not found -- ignored.'
          endif
          use
       endif
    endif
endif
return                                 && and return
```

```
**************************** estimate.prg ***************************
****** for each machine in each task check if the cost and capacity is
****** known, if they are read them
****** if not estimate the cost and capacity for the machine in each
****** operation the purpose of this program is to construct a database
****** file which has cost and capacity information for each machines in
****** each operation
**********************************************************************
******
set talk off
set procedure to cnvmoney
set alternate to linpro.dat
blank = .f.                      && define a true false variable for
cnvmoney

******************** PUBLIC VARIABLE DECLARATION **********************
********* NOTE all public variables are in upper case letters
****  some  other  public  variables  are  created  in  area.prg
********************
public D_SKID_SPD               && default skid speed, km/h
public D_RTRN_SPD               && default return speed, km/h
public D_SKID_DIS               && default skid distance
public SKID_RESIS               && skid resistance
public MAX_CHOKES               && maximum number of chokes per machine
public TIRE_LIFE                && average tire life, hours
public UNLOD_TIME               && time to unload a haul, minutes
public HOURS                     && maximum hours per year a machine is
used
public INT_RATE                && interest rate, decimal (eg. 0.1 = 10%)
public TSI_RATE                 && annual taxes, shelter, and insurance
                                && decimal value of purchase price
public TIRE_COST                && tire cost per hour
                                && decimal value of purchase price
public RM_COST                  && repair and maintenance rate per hour
                                && decimal value of purchase price
public GAS_PRICE               && gasoline price, base money units/liter
public DSL_PRICE                && diesel price, base money units/liter
public SALVACE                 && salvage value as a decimal of purchase
                                && price
public REPUTA_WT                && weight given to dealer's reputation
public PARTS_WT                 && weight given to parts support
public TRAIN_WT                 && weight given to training support
public SERVICE_WT               && weight given to service support
public FAMILR_WT                && weight given to machine familiarity
public COOLINC_WT              && weight given to machine cooling system
public FILTER_WT                && weight given to machine filtration
                                && system
public SUIT_WT                         && weight given to machine type
```

```
suitability
public RATING                       && overall rating of the machine
public BASIC_LIFE                   && basic life of this type of machine
public TRACT_EFF                    && tractive efficiency of this type of
                                    && machine
public LIFE                         && the machine life in hours
public PRICE                        && machine price
public AVAILABLE                    && number of hours/year machine is
                                    && available
public FIXED_COST                   && the machine fixed cost
public TASK_CAP                     && capacity of the machine in a task
public VAR_COST                     && variable cost of performing a task
public LOAD_FACT                    && machine load factor in a task
public NUM_TASKS                    && number of active tasks
public SUB                          && subscript for tasks
public SUITABLE                     && machine type suitability
***********************************************************************

do ld_skid                          && load the skid parameters
do area                             && compute the areas for each task
do ld_econ                          && load the economic data
do ld_wts                           && load the weighting constants

select a
use machines

&& write number of machines to output file
set alternate on
? reccount()                                && write # of machines to output
file
set alternate off
select c
use cost_cap
select a
do while .not. eof()
    do machtype                             && get the machine type info

    && determine the overall rating of this machine (0-100)
    do rating

    do life                                 && get the machine life
    do fcost                                && get the fixed cost

    i = 1                                   && i is the task index
    do while i <= NUM_TASKS
        SUB = ltrim(str(i))
        select c
        goto top
```

```
        && search if there is cost and/or capacity information for this
        && machine in this task
        locate for mach_no = machines->mach_no .and. ;
                   task_no = TASK_NUM&sub

        && get the capacity, estimate if necessary
        do capacity

        && get the variable cost, estimate if necessary
        do vcost

        && write the capacity and cost information to a file
        set alternate on
        set decimals to 2
        set fixed on
        ? (VAR_COST+LOAD_FACT/.8*FIXED_COST)
        set decimals to 4
        ?? TASK_CAP
        set fixed off
        set alternate off
        i = i + 1
    enddo
    select a
    skip                          && go to the next machine
enddo
close alternate
close all
! newpro < linpro.dat            && go execute the linear program to
                                 && select the least cost machinery set
**********************   e n d   o f   e s t i m a t e . p r g
*****************************
```

APPENDIX C

LINEAR PROGRAMMING, Lp.C PROGRAM

```
/* program lp.c -- linear programming for logging equipment selection*/
/* minimization (least cost) version */
/* ecy 1/89 */

#include <stdio.h>
#include <math.h>

#define MAX_N_MACHINES 35
#define MAX_N_TASKS 4
#define MAX_N_CONSTRAINTS  (MAX_N_TASKS + MAX_N_MACHINES)
#define MAX_N_ROWS  (MAX_N_CONSTRAINTS + 1)
#define MAX_N_REAL_VARIABLES  (MAX_N_TASKS * MAX_N_MACHINES)
#define MAX_N_VARIABLES (MAX_N_REAL_VARIABLES + MAX_N_CONSTRAINTS)
#define MAX_N_COLUMNS  (MAX_N_VARIABLES + 1)
#define FALSE 0
#define TRUE !FALSE
#define MAX_ITERATIONS (n_machines + 20)

/* NOTE these variables are gobal */
int  n_tasks, n_variables, n_constraints, n_machines, n_real_variables;
int n_rows, n_columns, p_row, p_column;
int j, row_out;
static float a[MAX_N_ROWS][MAX_N_COLUMNS];
static float hpu[MAX_N_MACHINES + 1];
static float reqarea[MAX_N_TASKS + 1], area[MAX_N_COLUMNS], aj, cost;
static int basis[MAX_N_ROWS], status[MAX_N_COLUMNS];
static char machname[MAX_N_MACHINES + 1][70], ch;
static char task_name[MAX_N_TASKS+1][70];
static int n_owned[MAX_N_MACHINES + 1], n_available[MAX_N_MACHINES + 1];
static int task_num[MAX_N_TASKS+1], mach_num[MAX_N_MACHINES+1];

main ()
{
        int i, k, iteration = 0, units[MAX_N_MACHINES + 1];
        static float hours[MAX_N_COLUMNS];
        float totarea[MAX_N_TASKS + 1], mach_hours;
        float zmin;

        void print();
        void build_tableau();
        void compute_cost();
        void STEP2();
        void STEP3_4();
        void STEP5_6();
        void STEP8();
        float round();

        build_tableau();        /* build the tableau for the problem */
        do                  /* do while the cost can be decreased */
          {
          compute_cost();                   /* compute the current cost */
          zmin = 0.;
          for (j=1; j <= n_variables; j++)
                {
                if (status[j]==0)                /* for each nonbasic vector */
                        {
                        STEP2();        /* determine its c[j] - z[j] */
                        STEP3_4();      /* determine the vector which would have to leave
                                                in order to maintain feasibility if this
                                                nonbasic vector were introduced into the
basis
                                                and determine the total change in variable
costs
                                                which would result. */

                        if ( aj < zmin )        /* select the most negative aj to add */
                                {
                                zmin = aj;              /* potential problem -- what happens */
                                p_column = j;           /* if 2 or more aj's are equal ?? */
                                p_row = row_out;        /* degeneracy */
                                }
```

```
                        }
                }

                /* STEP 7 if zmin ( the minimum cost reduction) is >= 0 go to
                        step 9 ( a local minimum has been reached).  If zmin is
                        negative that vector should enter the basis */

                if ( zmin < 0.0 )
                        {
                        printf("iteration = %d   cost = %10.0f     pivot row = %d   pivot column =
%d\n",
                                        iteration, cost, p_row, p_column);
                        STEP8();        /* perform the simplexing */
                        iteration++;
                        }
        }
        while ( (zmin < 0.0) && (iteration < MAX_ITERATIONS) );

        if (iteration == MAX_ITERATIONS)
                printf("Terminating after %d iterations\n", MAX_ITERATIONS);

        /* STEP 9 print out optimal solution */
        /* compute the new hourly usage */
        for ( i=1; i <= n_constraints; i++)
                hours[basis[i]] = a[i][0];

         printf("\n\nmachine usage (hours)\n");
         for (i=1, k = 1; i<=n_machines; i++)
                {
                mech_hours = 0.;
                printf("machine %d  ",mech_num[i]);
                for (j=1; j <= n_tasks; j++, k++)
                        {
                        printf("%7.0f  ",hours[k]);
                        mech_hours += hours[k];
                        }
                printf("\n");
                units[i] = (int) ceil( round(mech_hours)/hpu[i]) ;
                }

         printf("\n\nmachine usage (hectares)\n");
         for (i=1, k = 1; i<=n_machines; i++)
                {
                printf("machine %d  ",mech_num[i]);
                for (j=1; j <= n_tasks; j++, k++)
                        {
                        if (i==1) totarea[j] = 0.;
                        printf("%8.0f  ",area[k]*hours[k]);
                        totarea[j] += area[k]*hours[k];
                        }
                printf("\n");
                }

    printf("\n\nmachine cost ($)\n");
        cost = 0.;
        for (i=1, k = 1; i<=n_machines; i++)
                {
                printf("machine %d  ",mech_num[i]);
                for (j=1; j <= n_tasks; j++, k++)
                        {
                        printf("%8.0f  ",hours[k]*a[0][k]);
                        cost += hours[k]*a[0][k];
                        }
                printf("\n");
                }
        printf("total cost = %10.0f\n\n", cost);

        for (j=1; j <= n_tasks; j++)
                {
                if (totarea[j] < 0.99 * reqarea[j])
                        printf("This   machinery   set   has   insufficient   capacity   in   task
```

```
%d.\n",task_num[j]);
                }
        printf("\n\nThe recommended machinery set consists of:\n\n");
        for (i=1; i <= n_machines; i++)
                {
                if (units[i] > 0)
                        printf("%2d --- %s", units[i], &machname[i][0]);
                }
        printf("\n\nActions required to assemble the recommended machinery set are:\n\n");
        for (i=1; i <= n_machines; i++)
                {
                if (units[i] > n_owned[i])
                        printf("BUY  %2d --- %s", units[i]-n_owned[i], &machname[i][0]);
                if (units[i] < n_owned[i])
                        printf("SELL %2d --- %s", n_owned[i]-units[i], &machname[i][0]);
                }
}

/* function to build the initial tableau */
void build_tableau ()
        {
        int i, j, k;
        float life, rating;
        /* read the number of tasks */
        scanf("%d\n",&n_tasks);
        for (i=1;i<=n_tasks;i++)
                {
                scanf("%d %f",&task_num[i], &reqarea[i]);
                fgets(&task_name[i][0],70,stdin);
                }
        /* read the number of machines being considered */
        scanf("%d", &n_machines);

        n_constraints = n_tasks + n_machines;
        n_real_variables = n_machines * n_tasks;
        n_variables    = n_real_variables + n_constraints;
        n_columns      = n_variables + 1;
        n_rows         = n_constraints + 1;

        if ( (n_rows > MAX_N_ROWS) || (n_columns > MAX_N_COLUMNS) )
                {
                printf("ERROR --- problem too big\n");
                printf("size limited to %d machines ", MAX_N_MACHINES);
                printf("and %d tasks.\n", MAX_N_TASKS);
                exit(-1);
                }

  /* this section of code constructs the initial tableau for the
        linear programming problem  */

        /* set the area to be covered in each task */
        for (i = 1; i <= n_tasks; i++)
                {
                a[n_machines+i][0] = reqarea[i];
                printf(" task %d --- %s",task_num[i],&task_name[i][0]);
                }
                printf("\n");

        /* generate the initial tableau entries for each machine */
        for (i=1, k=1; i<= n_machines; i++)
                {
                do
                        ch = getchar();
                while (ch != '\n');
                fgets(&machname[i][0], 70, stdin); /* get the machine name */
                scanf("%d", &mach_num[i]);  /* machine id number */
                scanf("%d", &n_owned[i]);   /* # of these machines owned */
                scanf("%d", &n_available[i]);   /* # of these machines available */
                scanf("%f",&hpu[i]);     /* max hours per unit */
                a[i][0] = hpu[i]*(n_owned[i] + n_available[i]); /* total hours available */
                scanf("%f %f", &life, &rating);
```

```
		printf(" machine %d --- %s",mach_num[i], &machname[i][0]);
		for ( j=1; j<= n_tasks; j++, k++)
			{

			/* read the operating cost for each task */
			scanf("%f",&a[0][k]); /* construct objective function */

			/* construct time available constraint */
			/* i.e. the time spent in each task should be
				<=  the time available */
			a[i][k] = 1.;

			/* construct the area equality constraints for each task */
			/* i.e. the area processed in each task must equal
				the specified amount */
			scanf("%f",&a[n_machines+j][k]);
			area[k] =   a[n_machines+j][k];
			}
		}

		/* set up the slack and artificial variables */
		for (i = 1; i <= n_constraints; i++)
			{
			/* set the initial basis */
			basis[i] = n_real_variables + i;
			status[n_real_variables+i] = 1;
			a[i][n_real_variables+i] = 1.;
			}

		/* set up the "cost" of the artificial variables */
		for (i = 1; i <= n_tasks; i++)
			a[0][n_real_variables + n_machines + i] = 1.e6;

	/* at this point the initial tableau is built! */
	}

void STEP2()
	{
	int i;

	/* for each nonbasic vector determine its c[j] - z[j] */
	cj = a[0][j];
	for (i = 1; i <= n_constraints; i++)
		cj -= a[i][j]*a[0][basis[i]];
	/* printf("  c[%d]-z[%d] = %f ", j, j, cj); */
	}

void STEP3_4()
	{
	int i;
	float theta;
	/* for each nonbasic vector determine the vector which would
			have to leave in order to maintain feasibility */
	/* and for each nonbasic vector determine the total change in
			variable costs which would result if that vector were
			introduced into the basis. */


	row_out = 0;
	theta = 1.e38;
	for (i = 1; i <= n_constraints; i++)
		{
		/* select the most negative limiting amt */
		/* if (a[i][j] > 0.)
			printf(" theta[%d][%d] = %f  ", i, j, a[i][0]/a[i][j]); */
		if ( (a[i][j] > 0.) && (a[i][0]/a[i][j] < theta) )
			{
			row_out = i;			/* row to be removed */
			theta = a[i][0]/a[i][j];
			}
		}
```

```
        sj = theta*sj;           /* total change in variable costs */
        /* printf("%d   sjv = %g", j, sj); */

        }

void STEP8()
        {
        /* STEP 8 perform the simplexing */
        float pivot, temp;
        int i, k;

        pivot = a[p_row][p_column];

        /* set the new basis */
        status[basis[p_row]] = 0;
        status[p_column] = 1;
        basis[p_row] = p_column;

        for ( i=1; i <= n_constraints; i++)
                {
                temp = a[i][p_column] / pivot;
                for (j=0; j <= n_variables; j++)
                        if ( i != p_row)
                                a[i][j] = a[i][j] - temp * a[p_row][j];
                }
        /* compute the new pivot row */
        for (j= 0; j <= n_variables; j++)
                a[p_row][j] = a[p_row][j]/pivot;
        }

/* function to print the matrix */
  void print ()
        {
        int i;
        for (i=0;i<n_rows;i++)
                {
                for (j=0;j<n_columns;j++)
                   printf("%7.1f ",a[i][j]);
                printf("\n");
                }
        }

void compute_cost()
        {
        int i, k;
        float temp;
        cost = 0.;
        for (i=1; i <= n_constraints; i++)
                cost += a[0][basis[i]]*a[i][0];
        }

float round(x)
        float x;
        {
        return ( floor (x+.5) );
        }
```

APPENDIX D

MACHINE SELECTION OUTPUTS

```
Apr  2 19:56 1989  select1.dat Page 1
        1
1 2620.00 FIRST THINNING
        21
IH 885                      4 W.D., 6 cyl.
  5 20 99           1725       5250           75
                          18.45           0.1762
IH 7120                     4 W.D., 6 cyl.
  7  2 99           1725       5250           75
                          28.22           0.1762
CAT 518                     Skidder
  9  2 99           2300      10000          100
                          28.23           0.1762
CAT 528                     Skidder
 10  1 99           2269       9865           99
                          36.05           0.1762
FORD 4610                   2 W.D., 4cyl
 22  4 99           1796       5468           78
                          18.00           0.1762
FORD 6610                   2 W.D., 4 cyl.
 24 10 99           1796       5468           78
                          19.37           0.1762
FORD TW5                    4 W.D., 6 cyl. with cab
 28  5 99           1874       5704           81
                          24.37           0.1762
FORD TW15                   4 W.D., 6 cyl. with cab
 29  2 99           1874       5704           81
                          25.76           0.1762
FORD TW25                   4 W.D., 6 cyl. with cab
 30  0 99           1874       5704           81
                          26.92           0.1762
FORD TW35                   4 W.D., 6 cyl. with cab
 31  0 99           1874       5704           81
                          28.82           0.1762
JD 440D                     skidder
 39  0 99           1946       8459           85
                          21.22           0.1762
JD 450D                     skidder
 40  0 99           1946       8459           85
                          23.10           0.1762
JD 640D                     skidder
 41  0 99           1946       8459           85
                          24.98           0.1762
JD 740D                     skidder
 42  0 99           1946       8459           85
                          33.08           0.1762
JD 2355                     2 W.D.
 53  0 99           1790       5449           78
                          15.67           0.1762
JD 4050                     2 W.D.
 59  0 99           1790       5449           78
                          24.63           0.1762
TJ 380A                     skidder    powershift
 64  2 99           1977       8595           86
                          28.03           0.1762
TJ 450B                     Skidder
```

```
 65  0 99       1977        8595          86
                      29.14          0.1762
TJ 550B                Skidder
 66  0 99       1977        8595          86
                      33.88          0.1762
TJ 240A                skidder    powershift
 68  0 99       1977        8595          86
                      24.50          0.1762
TJ 230A                Skidder
 70  0 99       1977        8595          86
                      21.97          0.1762

 task 1 --- FIRST THINNING

 machine 5 --- IH 885               4 W.D., 6 cyl.
 machine 7 --- IH 7120              4 W.D., 6 cyl.
 machine 9 --- CAT 518              Skidder
 machine 10 --- CAT 528             Skidder
 machine 22 --- FORD 4610           2 W.D., 4cyl.
 machine 24 --- FORD 6610           2 W.D., 4 cyl.
 machine 28 --- FORD TW5            4 W.D., 6 cyl. with cab
 machine 29 --- FORD TW15           4 W.D., 6 cyl. with cab
 machine 30 --- FORD TW25           4 W.D., 6 cyl. with cab
 machine 31 --- FORD TW35           4 W.D., 6 cyl. with cab
 machine 39 --- JD 440D             skidder
 machine 40 --- JD 450D             skidder
 machine 41 --- JD 640D             skidder
 machine 42 --- JD 740D             skidder
 machine 53 --- JD 2355             2 W.D., 4cyl.
 machine 59 --- JD 4050             2 W.D., 4cyl.
 machine 64 --- TJ 380A             skidder  powershift
 machine 65 --- TJ 450B             Skidder
 machine 66 --- TJ 550B             Skidder
 machine 68 --- TJ 240A             skidder  powershift
 machine 70 --- TJ 230A             Skidder
iteration = 0   cost = 2620000000    pivot row = 22   pivot column = 15


machine usage (hours)
machine 5          0
machine 7          0
machine 9          0
machine 10         0
machine 22         0
machine 24         0
machine 28         0
machine 29         0
machine 30         0
machine 31         0
machine 39         0
machine 40         0
machine 41         0
machine 42         0
machine 53     14869
machine 59         0
machine 64         0
```

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```
machine 65        0
machine 66        0
machine 68        0
machine 70        0


machine usage (hectares)
machine 5          0
machine 7          0
machine 9          0
machine 10         0
machine 22         0
machine 24         0
machine 28         0
machine 29         0
machine 30         0
machine 31         0
machine 39         0
machine 40         0
machine 41         0
machine 42         0
machine 53      2620
machine 59         0
machine 64         0
machine 65         0
machine 66         0
machine 68         0
machine 70         0


machine cost ($)
machine 5          0
machine 7          0
machine 9          0
machine 10         0
machine 22         0
machine 24         0
machine 28         0
machine 29         0
machine 30         0
machine 31         0
machine 39         0
machine 40         0
machine 41         0
machine 42         0
machine 53    233005
machine 59         0
machine 64         0
machine 65         0
machine 66         0
machine 68         0
machine 70         0
total cost =     233005
```

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The recommended machinery set consists of:

9 --- JD 2355 2 W.D. 4cyl.

Actions required to assemble the recommended machinery set are:

SELL 20 --- IH 885	4 W.D., 6 cyl.
SELL 2 --- IH 7120	4 W.D., 6 cyl.
SELL 2 --- CAT 518	Skidder
SELL 1 --- CAT 528	Skidder
SELL 4 --- FORD 4610	2 W.D., 4cyl
SELL 10 --- FORD 6610	2 W.D., 4 cyl.
SELL 5 --- FORD TW5	4 W.D., 6 cyl. with cab
SELL 2 --- FORD TW15	4 W.D., 6 cyl. with cab
BUY 9 --- JD 2355	2 W.D., 4 cyl.
SELL 2 --- TJ 380A	skidder powershift

```
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        4
1 2620.00 FIRST THINNING
2 2474.00 SECOND THINNING
3 2299.00 THIRD THINNING
4 2379.00 FINAL CUT
         21
IH 885                  4 W.D., 6 cyl.
  5 20 99       1725         5250          75
                        18.45           0.1762
                        25.84           0.3056
                        25.84           0.0796
                        25.84           0.0425
IH 7120                 4 W.D., 6 cyl.
  7  2 99       1725         5250          75
                        28.22           0.1762
                        37.12           0.3161
                        53.02           0.1285
                        53.02           0.0755
CAT 518                 Skidder
  9  2 99       2300          10000        100
                        28.23           0.1762
                        35.57           0.3161
                        49.21           0.1306
                        49.21           0.0770
CAT 528                 Skidder
 10  1 99       2269          9865          99
                        36.05           0.1762
                        44.76           0.3161
                        68.67           0.1532
                        68.67           0.0948
FORD 4610               2 W.D., 4cyl.
 22  4 99       1796         5468          78
                        18.00           0.1762
                        19.06           0.2058
                        19.06           0.0518
                        19.06           0.0263
FORD 6610               2 W.D., 4 cyl.
 24 10 99       1796         5468          78
                        19.37           0.1762
                        24.56           0.2621
                        24.56           0.0673
                        24.56           0.0351
FORD TW5                4 W.D., 6 cyl. with cab
 28  5 99       1874         5704          81
                        24.37           0.1762
                        32.58           0.3161
                        38.40           0.1003
                        38.40           0.0556
FORD TW15               4 W.D    6 cyl. with cab
 29  2 99       1874         5704          81
                        25.76           0.1762
                        33.95           0.3161
                        43.75           0.1128
                        43.75           0.0641
FORD TW25               4 W.D  6 cyl. with cab
```

```
 30   0 99       1874        5704          81
                        26.92          0.1762
                        35.30          0.3161
                        48.79          0.1238
                        48.79          0.0720
FORD TW35              4 W.D     6 cyl. with cab
 31   0 99       1874        5704          81
                        28.82          0.1762
                        37.74          0.3161
                        56.60          0.1378
                        56.60          0.0825
JD 440D                skidder
 39   0 99       1946        8459          85
                        21.22          0.1762
                        27.89          0.3161
                        33.06          0.1019
                        33.06          0.0567
JD 450D                skidder
 40   0 99       1946        8459          85
                        23.10          0.1762
                        29.95          0.3161
                        38.16          0.1128
                        38.16          0.0641
JD 640D                skidder
 41   0 99       1946        8459          85
                        24.98          0.1762
                        32.15          0.3161
                        44.23          0.1259
                        44.23          0.0735
JD 740D                skidder
 42   0 99       1946        8459          85
                        33.08          0.1762
                        41.69          0.3161
                        61.91          0.1427
                        61.91          0.0863
JD 2355                2 W.D.
 53   0 99       1790        5449          78
                        15.67          0.1762
                        17.19          0.2138
                        17.19          0.0540
                        17.19          0.0275
JD 4050                2 W.D.
 59   0 99       1790        5449          78
                        24.63          0.1762
                        34.33          0.3161
                        36.57          0.0884
                        36.57          0.0479
TJ 380A                Skidder    Powershift
 64   2 99       1977        8595          86
                        28.03          0.1762
                        35.72          0.3161
                        50.29          0.1314
                        50.29          0.0776
TJ 450B                Skidder
 65   0 99       1977        8595          86
                        29.14          0.1762
```

```
                  37.16           0.3161
                  56.28           0.1447
                  56.28           0.0879
TJ 550B          Skidder
 66  0 99     1977      8595        86
                  33.88           0.1762
                  42.66           0.3161
                  66.46           0.1521
                  66.46           0.0938
TJ 240A          Skidder    Powershift
 68  0 99     1977      8595        86
                  24.50           0.1762
                  31.55           0.3161
                  42.76           0.1234
                  42.76           0.0717
TJ 230A          Skidder
 70  0 99     1977      8595        86
                  21.97           0.1762
                  28.64           0.3161
                  35.14           0.1070
                  35.14           0.0601

 task 1 --- FIRST THINNING
 task 2 --- SECOND THINNING
 task 3 --- THIRD THINNING
 task 4 --- FINAL CUT

 machine 5 --- IH 885              4 W.D., 6 cyl.
 machine 7 --- IH 7120             4 W.D., 6 cyl.
 machine 9 --- CAT 518             Skidder
 machine 10 --- CAT 528            Skidder
 machine 22 --- FORD 4610          2 W.D 4cyl
 machine 24 --- FORD 6610          2 W.D   4 cyl.
 machine 28 --- FORD TW5           4 W.D   6 cyl. with cab
 machine 29 --- FORD TW15          4 W.D   6 cyl. with cab
 machine 30 --- FORD TW25          4 W.D  6 cyl. with cab
 machine 31 --- FORD TW35          4 W.D    6 cyl. with cab
 machine 39 --- JD 440D            skidder
 machine 40 --- JD 450D            skidder
 machine 41 --- JD 640D            skidder
 machine 42 --- JD 740D            skidder
 machine 53 --- JD 2355            2 W.D.
 machine 59 --- JD 4050            2 W.D.
 machine 64 --- TJ 380A            Skidder   Powershift
 machine 65 --- TJ 450B            Skidder
 machine 66 --- TJ 550B            Skidder
 machine 68 --- TJ 240A            Skidder    Powershift
 machine 70 --- TJ 230A            Skidder
iteration = 0   cost = 9772000256   pivot row = 22   pivot column = 57
iteration = 1   cost = 7152232960   pivot row = 23   pivot column = 58
iteration = 2   cost = 4678431744   pivot row = 25   pivot column = 44
iteration = 3   cost = 2300818944   pivot row = 24   pivot column = 59


machine usage (hours)
machine 5         0        0        0        0
```

machine 7	0	0	0	0
machine 9	0	0	0	0
machine 10	0	0	0	0
machine 22	0	0	0	0
machine 24	0	0	0	0
machine 28	0	0	0	0
machine 29	0	0	0	0
machine 30	0	0	0	0
machine 31	0	0	0	0
machine 39	0	0	0	41958
machine 40	0	0	0	0
machine 41	0	0	0	0
machine 42	0	0	0	0
machine 53	14869	11572	42574	0
machine 59	0	0	0	0
machine 64	0	0	0	0
machine 65	0	0	0	0
machine 66	0	0	0	0
machine 68	0	0	0	0
machine 70	0	0	0	0

machine usage (hectares)

machine 5	0	0	0	0
machine 7	0	0	0	0
machine 9	0	0	0	0
machine 10	0	0	0	0
machine 22	0	0	0	0
machine 24	0	0	0	0
machine 28	0	0	0	0
machine 29	0	0	0	0
machine 30	0	0	0	0
machine 31	0	0	0	0
machine 39	0	0	0	2379
machine 40	0	0	0	0
machine 41	0	0	0	0
machine 42	0	0	0	0
machine 53	2620	2474	2299	0
machine 59	0	0	0	0
machine 64	0	0	0	0
machine 65	0	0	0	0
machine 66	0	0	0	0
machine 68	0	0	0	0
machine 70	0	0	0	0

machine cost ($)

machine 5	0	0	0	0
machine 7	0	0	0	0
machine 9	0	0	0	0
machine 10	0	0	0	0
machine 22	0	0	0	0
machine 24	0	0	0	0
machine 28	0	0	0	0
machine 29	0	0	0	0
machine 30	0	0	0	0

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machine 31	0	0	0	0
machine 39	0	0	0	1387121
machine 40	0	0	0	0
machine 41	0	0	0	0
machine 42	0	0	0	0
machine 53	233005	198915	731848	0
machine 59	0	0	0	0
machine 64	0	0	0	0
machine 65	0	0	0	0
machine 66	0	0	0	0
machine 68	0	0	0	0
machine 70	0	0	0	0
total cost =	2550889			

The recommended machinery set consists of:

22 —— JD 440D	skidder
39 —— JD 2355	2 W.D.

Actions required to assemble the recommended machinery set are:

SELL 20 —— IH 885	4 W.D., 6 cyl.
SELL 2 —— IH 7120	4 W.D., 6 cyl.
SELL 2 —— CAT 518	Skidder
SELL 1 —— CAT 528	Skidder
SELL 4 —— FORD 4610	2 W.D 4cyl
SELL 10 —— FORD 6610	2 W.D 4 cyl.
SELL 5 —— FORD TW5	4 W.D 6 cyl. with cab
SELL 2 —— FORD TW15	4 W.D 6 cyl. with cab
BUY 22 —— JD 440D	skidder
BUY 39 —— JD 2355	2 W.D.
SELL 2 —— TJ 380A	Skidder Powershift

A LOGGING EQUIPMENT SELECTION SYSTEM FOR INDUSTRIAL PLANTATIONS IN DEVELOPING COUNTRIES

by

WILFRED CHOKENI SINGOGO

Diploma - Forestry, Zambia Forest College, Kitwe, 1968
B.S., Oklahoma State University, 1986

AN ABSTRACT OF A THESIS

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MASTER OF SCIENCE

Department of Agricultural Engineering
(Mechanization)

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Manhattan, Kansas

1989

Abstract

The selection of logging equipment which is both efficient and economic is one of the most important decisions a logging manager or machine manager must make. Selection of the most appropriate machinery set for varying operating conditions and economic factors requires that operating cost data be considered and analyzed. A computer-based logging equipment selection program has been developed to aid logging managers or forest machine managers in planning ground-skidding operations in a plantation in developing countries.

The primary objective of this study was to develop a method to assist logging managers in the selection of optimum machinery sets for ground skidding in forest plantations. In order to accomplish this, it was necessary to develop a method of assessing equipment suitability for local conditions. The assessment procedure was incorporated into a computer program called the Logging Equipment Selection System (LESS). A secondary objective was to demonstrate the applicability of this program using a limited database of logging equipment.

The program provides an efficient means of estimating skidding system costs, production capacities and equipment performance. LESS is a combination of a database program and a linear programming model. LESS determines the least cost machinery set necessary for a given set of skidding operations, taking into account both the fixed and variable costs associated with owning and operating the machinery. Finally, the program makes

recommendations to "keep," "sell," or "buy" the equipment evaluated.